Effects of Sound on the Marine Environment: Rapid Assessment

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LONG-TERM GOALS

To develop novel techniques to predict the impact of sound on the marine environment and use natural sound sources (such as whale calls) to observe non-invasively both animal behavior and the marine environment.

OBJECTIVES

The central objective is to develop a prototype simulation system using the latest ocean acoustic models suitable for propagation modeling in a wide variety of environments and with different sounds sources. The latter will address both the commonly used navy SONAR sources, as well as those used by the research community. An automated set of acoustic model selection rules will be provided taking into account source parameters, environmental conditions, run-time, and required output (e.g. waveform vs. intensity). The models will be modified as needed to provide for directional sources and allow for Monte-Carlo simulations to quantify the variability. The models will be tested in particular sites to both demonstrate the end-to-end processing and validate the algorithms.

APPROACH

The author has participated in several ESME workshops to lay out the broad requirements of the simulation system taking into account characteristics of navy SONAR systems as well as available knowledge to characterize sound levels with potential impact on marine mammals. The ESME group collectively converged on the Southern California Bight as a site for a prototype simulation effort. Secondly, in collaboration with Chris Tiemann (SAIC) and with additional support from the CEROS program, we have obtained acoustic data from the Pacific Missile Range Facility (PMRF) during the humpback whale, winter breeding season.

WORK COMPLETED

A website (http://oalib.saic.com/Whales/) has been constructed with a subsection specifically devoted to the Southern California Bight. Environmental and other input data were provided by other ESME participants. This included the ocean bottom (J. Miller, URI); the oceanography (G. Gawarkiewicz, WHOI), and the SONAR sources (W. Carey, BU).

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14. ABSTRACT
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15. SUBJECT TERMS

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A baseline simulation was then assembled; first rendering the 3D oceanographic structure from which a mean sound-speed profile was extracted. Illustrative ray trace and transmission loss plots were then constructed. Finally, an LFM source waveform typical of a navy low-frequency SONAR system was generated and fed into the BELLHOP ray/beam model. The output is an ensemble of simulated waveforms that a mammal might hear at a sequence of 10 different ranges. This output then became the input to a finite-element simulation (developed by D. Mountain, BU) of the head of whale.

As the final production system is being assembled at NRL, a second part of this effort was to transition the modeling tools and information on their use to the NRL team. Considering the requirements of the overall simulation system a set of 3 models was selected. This included the BELLHOP beam tracing model; the KRAKEN3D/WRAP normal mode model, and the RAM parabolic equation model. These models represent the state of the art in ocean acoustic modeling. Each has significantly different characteristics allowing efficient simulation of a variety of navy SONAR systems.

As a separate test site, we have also processed data from PMRF and developed an automated alert system to first detect the presence of marine mammals by their calls. Secondly, we have incorporated one of the acoustic models in a preliminary tracking process that will ultimately be used for behavioral studies of humpback whales.

RESULTS

The principal result of this effort is the transition of appropriate modeling tools and information on their use to NRL. Here we can summarize the results of the pilot study. The oceanographic information for the Southern California Bight was provided by Glen Gawarkiwicz, WHOI using data from the California Coastal Fisheries program. This data was rendered as shown in Fig. 1.

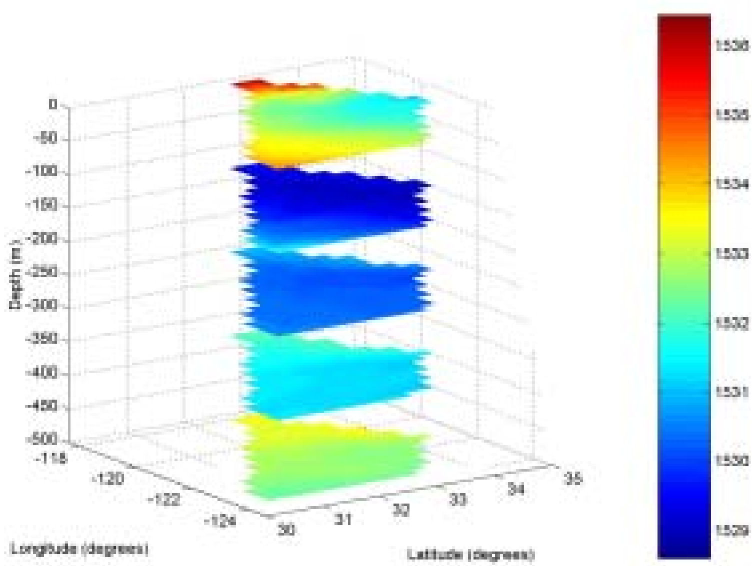

Figure 1: Sound speed structure in the Southern California Bight.

Selecting the central or carrier frequency of 400 Hz, we next used the BELLHOP ray/beam tracing code to predict the transmission loss for this environment. The result shown in Fig. 2 shows the resulting pattern with regions of high and low intensity in focal and shadow regions respectively.

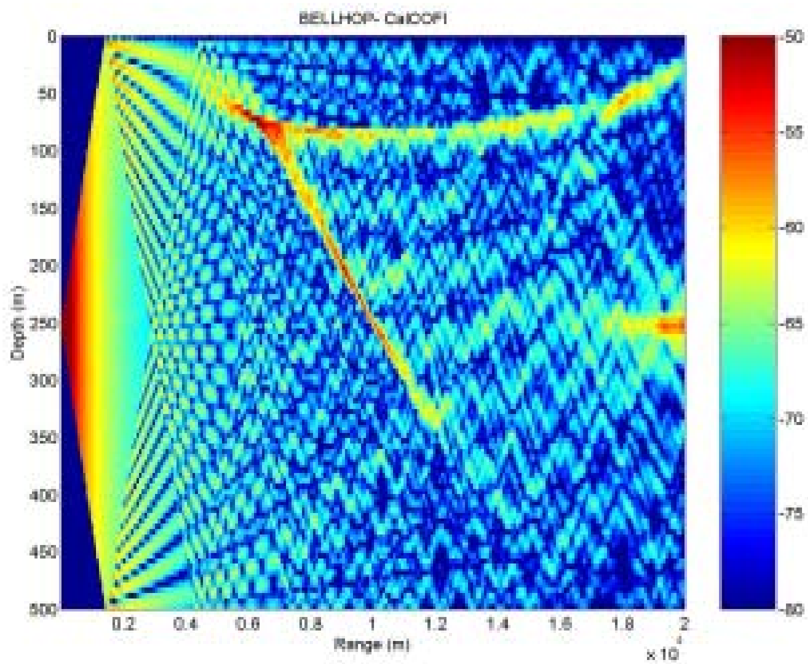

Figure 2: Transmission loss for a 400 Hz source at mid-water depth.

The BELLHOP model was selected for the initial simulations particularly because it is well-suited for propagating the full time series through the ocean environment (rather than just producing intensity at the carrier frequency). In brief, the model produces the levels and time lags associated with each echo so that the received time series is built up by simply delaying and summing echoes of the source waveform.

Based on discussions summarizing typical navy SONAR (W. Carey, BU) an LFM pulse was selected, sweeping from 380-420 Hz over a 17.5 second period. The source waveform is displayed on the left in Fig. 3. Propagating the SONAR pulse through the acoustic model yields the time-series shown on the right in Fig. 3. The result indicates both the overall level of the received energy as well as the interference pattern. The latter is significant since it is believed by some that short bursts of high-intensity sound may be more damaging than an energy-equivalent waveform whose energy is distributed over a longer time. The BU group is currently processing this acoustic data using a finite-element model of a mammal head to develop a simple metric for temporary threshold shift.

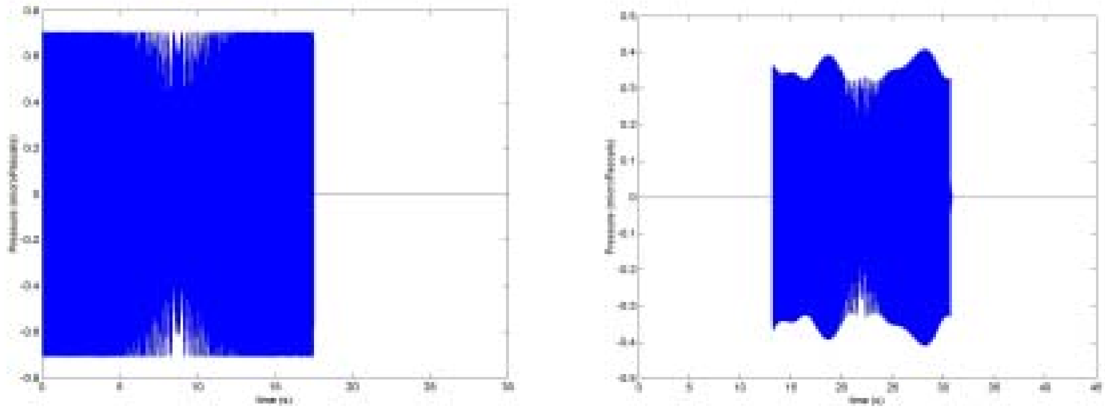

Figure 3: Source time series (left) for an LFM sweeping from 380-420 Hz over 17.5 seconds.. Received time series (right) at a range of 20 km (boosted by 50 dB for display)

Recorded audio from the Pacific Missile Range Facility was also processed using the BELLHOP model. In particular, several days of acoustic data were recorded last March during the humpback breeding season. The site with the locations of the 6 hydrophones is shown on the left in Fig. 4. Singers were present essentially continuously in the data.

Correlating the spectrograms between all possible pairs of hydrophones yielded a time lag for each pair. The BELLHOP model then predicted the time lag for each candidate singer location. Comparing the measured time-lags to the predicted ones yields a so-called 'ambiguity surface' whose peak corresponds to the position of the source. In this fashion a movie is produced showing the tracks of the loudest singers. A snapshot from the sequence is shown on the right in Fig. 4.

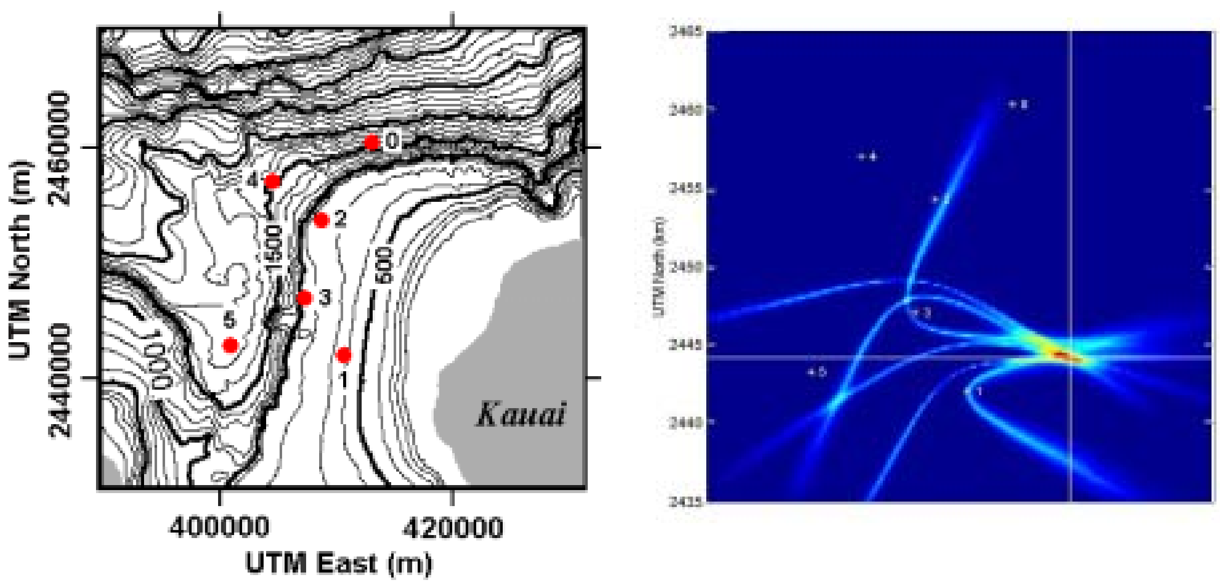

Figure 4: Humpback whale calls received on a set of hydrophones at the Pacific Misile Range Facility (left) are cross-correlated to yield a set of arrival-time difference on phone pairs. Comparing those arrival times to predictions from the BELLHOP beam-tracing model enables the calls to be located in lat-long. space (right).

IMPACT/APPLICATIONS

This work is intended to develop a state-of-the-art simulation system to predict the effects of sound on the marine environment. There is at least scattered evidence that anthropogenic sound is affecting the behavior of marine mammals. The major source is probably commercial shipping; however, modern active SONAR may also be disturbing or even dangerous to marine mammals. This research reflects increasing sensitivity to activities potentially affecting the marine environment.

TRANSITIONS

The acoustic modeling tools are being integrated by the NRL team in the baseline simulator destined for transition to OPNAV N45.

RELATED PROJECTS

The Center for Excellence in Research on Oceanographic Sciences provided additional support for the whale tracking effort at the Pacific Missile Range Facility including the development of the real-time data acquisition system.

PUBLICATIONS

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[3] M.B. Porter, V.M. McDonald, J. Rice, P. Baxley, "Channel characterization for high-frequency acoustic communications", (invited talk) *J. Acoust. Soc. Am.*, Vol. **109**(5):2449, Pt. 2 (2001).

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